Fatigue Risk Management: Assessing and Ranking the Factors Affecting the Degree of Fatigue and Sleepiness of Heavy-Vehicle Drivers Using TOPSIS and Statistical Analyses

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RESEARCH PAPER

Fatigue Risk Management: Assessing and Ranking the Factors Affecting the Degree of Fatigue and Sleepiness of Heavy-Vehicle Drivers Using TOPSIS and Statistical Analyses

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Abstract
This descriptive–analytic study identified the factors affecting the degree of fatigue and sleepiness of heavy-vehicle drivers, assessed their effects, and ranked them according to extent of influence by using statistical analysis and the technique for order of preference by similarity to ideal solution (TOPSIS). Data were collected through interviews guided by a questionnaire, through which three main categories of factors that contribute to crashes caused by fatigue and sleepiness were discussed. These categories are (I) human, (II) road and environmental conditions, and (III) vehicle-related factors. The results showed that human and road and environmental conditions exert the strongest and weakest effects, respectively. The statistical and TOPSIS results revealed that the first four factors that exert the strongest effects are inappropriate behaviors of passengers and goods owners, non-standard roads, inappropriate behaviors of police, and economic problems of heavy-vehicle drivers.

Keywords Heavy vehicle · Fatigue management · Statistical analysis · TOPSIS analysis

1 Introduction

Fatigue has been identified as a contributing factor to accidents, injuries, and deaths in a wide range of activities, including jobs that require continuous labor and long work hours (e.g., road transport, aviation, railway and marine employment, hospital and emergency work). In road transport, fatigue diminishes driving efficiency and increases the probability of accidents or injuries. Fatigue-related effects, such as decreased reaction time, loss of consciousness, and inaccurate information processing, have been determined as the causes of many accidents. The main symptoms of driver fatigue include sleepiness and heaviness in eyelids, deviations from paths, disregarding road signs, restlessness and irritability, acceleration and unusual braking, the need to take short naps, and difficulty in maintaining vehicle trajectory when moving between lanes (Williamson et al. 2011). Fatigue has also been identified as a mechanism that links a kind of stress related to working conditions (job strain and low social support) to risky driving (Useche et al. 2017).

In many countries, fatigue has contributed to a significant proportion of road accidents, but estimates regarding its role in accident severity and its association with environmental conditions are highly variable. In Britain, for example, accidents involving fatigue account for 20% of all accidents occurring on main roads (Horne and Reyner 1995). In the USA, the National Highways Traffic Safety Administration estimated that each year, 56,000 accidents are caused by sleepiness, resulting in 40,000 injuries and 1550 fatalities (Liu et al. 2009). In Australia, accident

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statistics from 1998 showed that 251 people (16.6% of all road fatalities) were killed in accidents caused by driver fatigue (Dobbie 2002). In New Zealand, statistical reports for 1996 to 1998 indicated that 8% of all fatal crashes and 5% of injury accidents were related to driver fatigue (Land Transport Safety Authority 1998). In Norway, interviews of 9200 accident-involved drivers showed that 9.3% of the crashes were related to driver fatigue and that about 20% of the accidents occurring at night were due to driver drowsiness (Sagberg 1999). Finally, various researchers have estimated that fatigue-related crashes account for up to 20% of serious crashes (Connor et al. 2002; Fernandes et al. 2010; Maclean et al. 2003).

In Iran, a particular issue of concern is the inferiority of road safety compared with that in other countries. In 2013, the rate of road fatalities per hundred thousand population in the country was 32.1, which is substantially higher than those in developed countries, such as the USA and Australia, which had fatality rates of 10.6 and 5.4, respectively (WHO 2015). According to statistical reports published by Iran's Center of Information and Communication of Police, fatigue and drowsiness contribute to 38% of fatal crashes on rural roads (ICPI 2015). These problems are further exacerbated by the inappropriateness of existing vehicles for the transport of goods and passengers and the lack of other forms of transportation modes. Heavy vehicles, such as trucks, trailers, and buses, are especially contributory to accidents that cause irreparable damages to the economy of the country.

Most experts believe that determining the contribution of fatigue to accidents is difficult because of the lack of simple and reliable evaluation methods for traffic law enforcers. Additionally, the degree of fatigue experienced by a driver cannot be accurately determined at the time of an accident. Thus, calculations of percentages made on the basis of crash data underestimate the true magnitude of fatigue-related road problems (Williamson et al. 2011). Examining the phenomenon of fatigue, preventing or mitigating its consequences, and identifying fruitful directions for research necessitate that studies be devoted to six related dimensions. These dimensions are the relationship between fatigue and safety, the association between demographic characteristics and fatigue, the modeling of fatigue, technological measures for determining driver fatigue, organizational approaches to fatigue management, and the ranking of factors that affect degree of fatigue. Efforts have been made in this regard. Williamson et al. (2011), for instance, examined the relationship between fatigue and safety by probing into three main causes of accidents (circadian influences, sleep homeostasis factors, and nature of task effects) and safety outcomes. The authors first looked into relationship between fatigue and accidents and injuries and then investigated its adverse effects on driver performance. Milia et al. (2011) analyzed the association between a number of demographic variables (e.g., age, sex, race and ethnicity, marital status, socio-economic status, personality traits) and fatigue and accident risk. The researchers also sought to understand the effects of work shift changes on preliminary work performance. Smolensky et al. (2011) investigated the role of various chronic medical conditions and sleep disorders in driver fatigue and road accident risk. Dawson et al. (2011) studied different theoretical models for predicting the circadian rhythm of sleep and fatigue. They also evaluated how fatigue models are applied in field settings by organizations. Williamson and Friswell (2013) showed that incentive-based payment and unpaid waiting in queues are significant predictors of driver fatigue in long-distance trucking. In another research, Friswell and Williamson (2013) examined and compared the fatigue experiences of drivers of short-haul light and long-distance heavy vehicles. The drivers of short-haul light vehicles indicated long daytime work hours, insufficiency of the number of rest breaks, urban traffic environments, and uncomfortable vehicle conditions as factors contributing to fatigue, whereas the drivers of long-distance heavy vehicles identified long work hours that extend into the night, dawn driving, and the time spent waiting to load and unload as fatigue factors. In their comparison of wage systems for heavy-vehicle drivers, Thompson et al. (2015) found that drivers paid through an incentive system (per kilometer or per trip) are more likely to drive while fatigued than those paid under a flat-rate wage system. The former are also more likely to increase their risks of being involved in crashes, being fined, and losing their license. Zhang et al. (2016) identified driving from midnight to dawn and driving during morning rush hours as risk factors for fatigue-related crashes, but they also stated that these factors do not necessarily result in severe casualties. Wang et al. (2018) found that the driving duration and rest patterns have significant impacts on the driver's visual behaviors, sleepiness awareness, and driving performance. Davidvic et al. (2018) found that body clock, sleep and work factors have an impact on drivers' fatigue. They mentioned working over the legal limit and sleep less than 6 h increases or the poor quality of drivers sleep eightfold. The poor quality of sleep reduces driver performance, and increases the crash risk.

In recent years, Naturalistic Driving Studies have been developed as a method of examining driver fatigue and traffic incidents. Using this method, Chen et al. (2016) evaluated the sleep patterns of truck drivers in non-work periods on truck driving performance. They found that sleep patterns such as short sleeping, sleeping during the early stage of a non-work period, and reduced sleep between 1 a.m. to 5 a.m. contribute the highest to the rate of occurrence of safety–critical events. In a naturalistic truck driving study conducted by Soccolich et al. (2013), the data analysis indicated that increased work hours (i.e., driving in addition to non-driving work) can increase the occurrence of safety–critical events. Gander et al. (2011) delved into fatigue risk management systems in the transportation industry. The researchers traced the evolution of regulatory frameworks, from uni-dimensional service regulation to frameworks that enable multi-dimensional fatigue risk management, in which the locus of responsibility for safety is shifted away from regulators and directed toward companies and individuals. Balkin et al. (2011) assessed the application of technological approaches in managing fatigue. The authors examined various available technologies for this purpose, highlighted the characteristics of an ideal system, and discussed human–device interaction issues, including user acceptance and compliance. Unlike the regulatory and organizational approaches described by Gander et al. (2011), technology-oriented methods concentrate on individual drivers, operators, or workers.

Grujicic et al. (2010) inquired into issues related to fatigue among heavy-vehicle drivers using musculoskeletal modeling and simulation methods. The researchers investigated the effects of several driver- and vehicle-related factors (including a driver's backrest inclination angle, coefficient of friction between a driver and a car seat, seat track position, presence or absence of lumbar support) with respect to controlling factors for driver fatigue (such as normal soft-tissue contact, maximum muscle activation, joint forces, and shear stresses). They also presented a long-distance driving fatigue function based on the aforementioned controlling factors. Liu and Wu (2008) studied the effects of road environments on the driving behavior and operation of fatigued drivers. Their results showed that the fatigued drivers were less conscious of their surroundings and tended to overestimate the distance indicated in roadside traffic signs. Fatigue due to driving on a complicated road environment exerted the greatest negative effect on driving behavior and visual distance estimation.

Apart from studies grounded in naturalistic driving principles, considerable research has been devoted to fatigue detection methods (Morad et al. 2009; Zheng et al. 2016; Fu et al. 2016, Knapik and Cyganek 2019) and countermeasures for driving fatigue (Ronen et al. 2014; Meng et al. 2016). An additional necessary requirement is to identify more factors to enable drivers and traffic law enforces to reduce the number of fatigue-related accidents through preventive countermeasures. The causes of driver fatigue can be classified into three categories, namely human, road and environmental conditions, and vehicle-related factors. On the basis of these categories, the current study investigated the most important factors affecting the degree of fatigue and sleepiness of heavy-vehicle drivers. Using statistical analysis and the technique for order of preference by similarity to ideal solution (TOPSIS, a multi-criteria decision-making method), we identified the aforementioned factors and ranked them according to extent of influence. The investigation was guided by the following questions: What factors affect accidents caused by the fatigue and sleepiness experienced by heavy-vehicle drivers? Among the three categories of factors, which exerts the strongest influence on driver fatigue? To reduce fatigue-related accidents, which factors should be considered in the development of countermeasures?

2 Methodology

To investigate the factors that affect the fatigue and sleepiness experienced by drivers, independent variables related to the three categories of factors ((I) human, (II) road and environmental conditions, and (III) vehicle-related factors) were selected. The selection was based on available data, the judgment of engineering experts, the experiences of drivers, and similar studies carried out in other countries.

This study is of a descriptive–analytic design, and the statistical population comprised freight- and passenger-vehicle drivers. The data collection tool was an interview guided by a questionnaire consisting of 41 questions (30 = closed-ended, 11 = opened-ended). The questionnaire was developed on the basis of previous studies on driver fatigue, research on the road transportation fleet system of Iran, the cultural situation of heavy-vehicle drivers, and consultations with the Khorasan Razavi Department of Road Maintenance and Transportation. In the first stage, the questionnaire was administered to a few drivers, after which the reliability of the instrument was assessed and modifications were applied where necessary. The revised questionnaire was filled in by the final sample of drivers with help from the researchers during the interviews. The final version of the questionnaire consisted of 18 questions, all of them were defined as closed-ended.

The reliability of the final questionnaire version was also measured.[1] The Cronbach's alpha coefficients of the questionnaire items were determined using the Statistical Package for the Social Sciences (SPSS) version 15. The coefficients are 0.817, 0.766, and 0.693 for human, road and environmental conditions, and vehicle-related factors, respectively. The validity of the questionnaire was ascertained via factor analysis and principal component analysis.[2] The suitability of the sample for factor analysis

[1] Reliability is defined as the extent to which a questionnaire produces the same results on repeated trials. That is, it refers to the stability or consistency of scores over time or across raters. Questionnaire reliability is most commonly measured using Cronbach's alpha, whose theoretical value varies from 0 to 1. Higher alpha values (≥ 0.7) are more desirable.

[2] Validity is defined as the extent to which a questionnaire measures what it purports to measure. Factor analysis is a statistical procedure used to identify a small number of factors that can be used to represent relationships among a set of interrelated variables.

Table 1 The confirmed results of assumptions of principal component analysis

The Kaiser–Meyer–Olkin (KMO)	0.773
Bartlett's test of sphericity	1611
Significance	0.000
Degrees of freedom	153

Table 2 The scoring range of effectiveness of independent variables on driver fatigue based on the Likert scale

Options	No effect	Very low	Low	Average	High	Very high (strong effect)
Likert scale	0	1	2	3	4	5

was determined using the Kaiser–Meyer–Olkin (KMO) measure,[3] and the significance of the correlation matrix was ascertained through Bartlett's test of sphericity.[4] A KMO below 0.5 indicates that a given sample is inappropriate for factor analysis. In this work, the KMO value is 0.773, indicating that the sample size is adequate. The result of the Bartlett's test of sphericity is significant, indicating that association probability is less than 0.05; that is, the significance level is small enough for us to reject the null hypothesis. In more direct terms, the correlation matrix is not an identity matrix. The results of the KMO measurement and Bartlett's test of sphericity are presented in Table 1.

After the above-mentioned procedures were completed, the most important factors among the three factor categories were determined. Finally, the independent variables affecting the fatigue and sleepiness of the heavy-vehicle drivers were ranked via a statistical analysis and TOPSIS. All the procedures for sample estimation, description, and data analysis were carried out using SPSS, the Statistical Analysis System, and Microsoft Excel.

3 Data Description

The statistical population is chosen from the Khorasan Razavi province of Iran. The Khorasan Razavi Department of Road Maintenance and Transportation (2017) reported that in 2016, the number of such drivers in the province was 48,177, among whom 39,663 and 8514 are freight- and passenger-vehicle drivers, respectively. Out of this group, 335 drivers (248 = freight-vehicle drivers, 87 = passenger-vehicle drivers) from seven counties were chosen for participation in the research on the basis of a statistical analysis, existing data, and two-stage cluster sampling.

Participants were recruited from passenger terminals, goods terminals, and gas stations. The selection was on volunteer basis. Participants were assured of the anonymity of their responses and their consent was obtained before fulfilling the questionnaires.

The effects of variables on driver fatigue were scored using a Likert scale ranging from 0 (no effect) to 5 (strong effect) (Table 2). A summary of the statistical description of variables is provided in Table 3.

4 Analysis

4.1 Effects of Human Factors on Driver Fatigue

The effects of the independent variables on fatigue and sleepiness were evaluated via questionnaire administrated/handed out to the 335 drivers. The human category comprises age and physical abilities of drivers, inappropriate behaviors of passengers and goods owners, inappropriate behaviors of police, diseases associated with poor physical abilities, drug and alcohol abuse, family problems (death of family members, family dispute, gloom, etc.), and economic problems (costs of living, house rental, loans, etc.). Participants' responses show that behaviors such as "multiple checking documents, incompatible fines for defective documents, violent and instructional behavior" are some kinds of inappropriate police behavior and "Violent and instructional behavior, talking impolitely, discussion to get a discount" are examples of inappropriate behaviors of passengers and goods owners.

The results are shown in Table 4. The minimum and maximum rates for driver fatigue due to human factors are 0 and 40 (5×8), respectively. The bars in Fig. 1 are compressed on the right side of the figure, and the skewness in Fig. 2 is located on the left, indicating that human factors strongly contribute to driver fatigue. For a better understanding of the effects of human factors on driver fatigue, the fatigue rate is illustrated qualitatively in Fig. 2. Accordingly, such effects were divided into three levels: weak (0–13.5), moderate (13.5–27), and strong (27–40).

[3] The KMO measure determines the sampling adequacy that is used to compare the magnitudes of observed correlation coefficients in relation to the magnitudes of partial correlation coefficients. Sampling adequacy can be interpreted as follows: 0.90 = marvelous, 0.80 = meritorious, 0.70 = middling, 0.60 = mediocre, 0.50 = miserable.

[4] Bartlett's test of sphericity tests the hypothesis that the correlation matrix is an identity matrix; that is, all diagonal elements are 1, and all off-diagonal elements are 0. If the significance value of this test is less than our alpha level (<0.05), then the null hypothesis (i.e., The population matrix is not an identity matrix.) can be rejected.

Table 3 Data description of the independent variables of human, road and environmental, vehicle factors on fatigue of heavy-vehicle drivers

Category	Independent variable	Minimum	Maximum	Average	Median	Mode	SD	Number of respondents
Human	Age and physical abilities of drivers	0	5	3.34	3	3	1.41	331
	Inappropriate behaviors of passengers and goods owners	0	5	3.88	4	5	1.18	329
	Inappropriate behaviors of police	0	5	3.98	5	5	1.33	332
	Diseases associated with poor physical abilities	0	5	2.98	3	4	1.45	329
	Drug abuse	0	5	3.77	4	5	1.67	319
	Alcohol abuse	0	5	3.89	5	5	1.69	315
	Family problems (death of family members, family dispute, gloom, …)	0	5	3.73	4	5	1.29	322
	Economic problems (costs of living, house rental, loans, …)	0	5	3.93	4	5	1.21	324
Road and environmental	Driving on uniform and long roads	0	5	2.86	4	4	1.45	332
	Driving on high-traffic routes	0	5	3.61	4	4	1.34	332
	Driving on non-standard roads with few road signs and poor quality asphalt pavement	0	5	3.85	4	4	1.29	334
	Driving in bad weather conditions (snow, fog, storm, etc.)	0	5	3.56	5	5	1.29	331
	Driving between the hours of 5 a.m. and 2–4 p.m.	0	5	3.01	4	5	1.54	333
Vehicle	Vehicle defects and age	0	5	3.49	4	4	1.40	334
	Shortage of appropriate driver cabin features (air conditioning and seating conditions)	0	5	3.49	4	4	1.35	333
	Excess freight and passengers carried	0	5	3.44	4	4	1.51	320
	Transport of contraband and associated stress and anxiety	0	5	4.01	5	5	1.53	317
	Type of loads carried (perishable goods, fruits and vegetables)	0	5	3.56	4	5	1.50	304

Table 4 The relative frequency of effectiveness of independent variables on driver fatigue

Category	Independent variable	No effect	Very low	Low	Ave.	High	Very high
Human	Age and physical abilities of drivers	5.4	6.3	11	27.5	23.9	24.8
	Inappropriate behaviors of passengers and goods owners	1.2	3.9	7.8	17	31.6	36.7
	Inappropriate behaviors of police	2.7	3.6	9	13.1	20.6	50.1
	Diseases associated with poor physical abilities	7.2	11.6	12.5	25.4	27.8	13.7
	Drug abuse	11	2.7	3.6	9	22.1	46.9
	Alcohol abuse	11	2.4	2.4	7.2	18.2	52.8
	Family problems (death of family members, family dispute, gloom, …)	3.3	2.7	9	20.3	27.5	33.4
	Economic problems (costs of living, house rental, …)	2.7	2.1	6	17.3	29	39.7
Road and environmental	Driving on uniform and long roads	10.1	8.1	14.9	29.9	24.8	11.3
	Driving on high-traffic routes	5.1	4.5	5.4	22.1	33.7	28.4
	Driving on non-standard roads with few road signs and poor quality asphalt pavement	2.7	3.9	8.1	16.4	28.4	40.3
	Driving in bad weather conditions (snow, fog, storm, etc.)	2.7	4.8	11.9	21.5	31	26.9
	Driving between the hours of 5 a.m. and 2–4 p.m.	10.1	9.6	10.4	26	25.7	17.6
Vehicle	Vehicle defects and age	5.1	6	9.9	19.7	32.8	26.3
	Shortage of appropriate driver cabin features (air conditioning and seating conditions)	3.9	5.4	10.7	25.1	27.2	27.2
	Excess freight and passengers carried	7.8	4.8	8.1	19.1	28.4	27.5
	Transport of contraband and associated stress and anxiety	7.5	3	2.7	9	18.2	54.3
	Type of loads carried (perishable goods, fruits and vegetables)	5.7	6.3	6	17.6	23.9	31.3

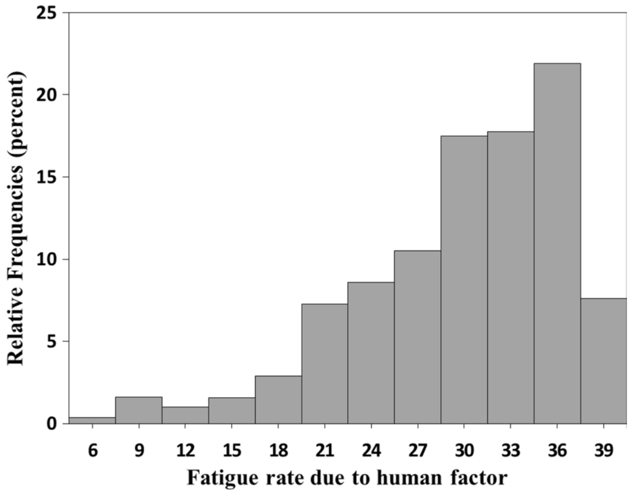

Fig. 1 Relative frequency of driver fatigue rate due to human factor (quantitatively)

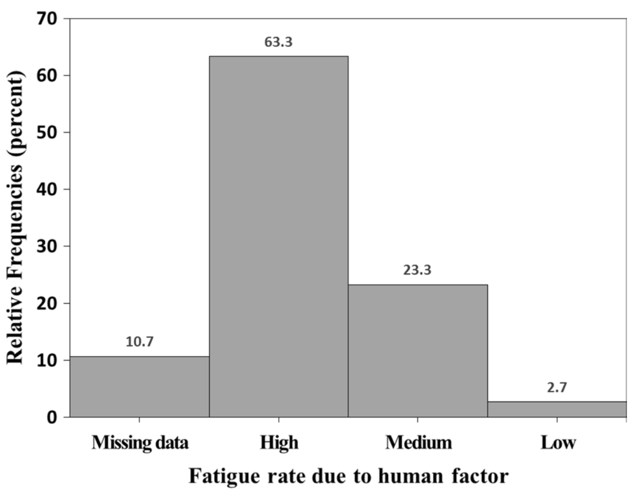

Fig. 2 Relative frequency of driver fatigue rate due to human factor (qualitatively)

As shown in Fig. 2, 63.3% of the drivers indicated that human factors strongly affect the degree of fatigue that they experience, whereas only 26% of the drivers stated that human factors exert weak and moderate effects.

4.2 Effects of Road and Environmental Conditions on Driver Fatigue

The road and environmental conditions category encompasses driving on uniform and long roads, driving on high-traffic routes, driving on non-standard roads with few road signs and poor-quality asphalt pavement, driving in bad weather conditions (snow, fog, storm, etc.), and driving

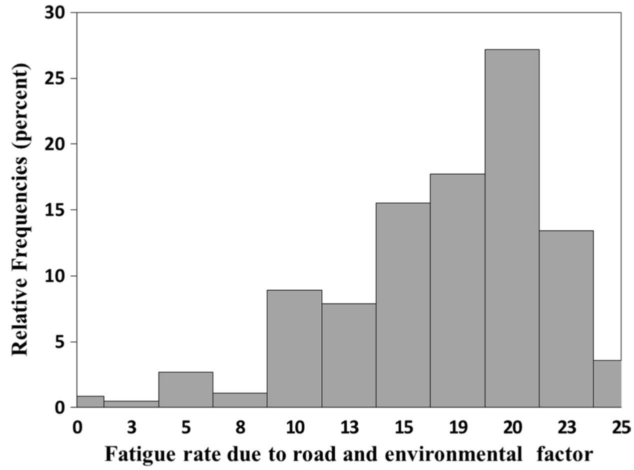

Fig. 3 Relative frequency of driver fatigue rate due to road and environmental factor (quantitatively)

between the hours of 0 and 5 a.m. and 2 to 4 p.m. These factors were scored using a Likert scale ranging from 0 (no effect) to 5 (strong effect). The findings are provided in Table 4. The minimum and maximum rates for driver fatigue due to road and environmental conditions are 0 and 25 (5×5), respectively. Figure 3 illustrates the relative frequency of the effects of road and environmental conditions on driver fatigue. To evaluate such effects, fatigue rate is described qualitatively in Fig. 4. Accordingly, the effects of road and environmental conditions on driver fatigue were divided into three levels: weak (0–8.5), moderate (8.5–17), and strong (17–25). Figure 4 indicates that 60.6% of the drivers evaluated the effects of road and environmental conditions as strong, whereas only 37% classified the effects as weak and moderate.

4.3 Effects of Vehicle-Related Factors on Driver Fatigue

The vehicle-related factors include vehicle defects and age, shortage of appropriate driver cabin features (air conditioning and seating conditions), excess freight and passengers carried, transport of contraband and associated stress and anxiety, and type of loads carried (perishable goods, fruits, and vegetables). These factors were also scored using a Likert scale ranging from 0 (no effect) to 5 (strong effect). The results are listed in Table 4. The minimum and maximum rates for driver fatigue due to vehicle-related factors are 0 and 25 (5×5), respectively. The skewness in Fig. 5 proceeds to the left, indicating that the aforementioned factors strongly affect driver fatigue. To illustrate the effects of vehicle-related factors on driver fatigue, the fatigue rate is described qualitatively in Fig. 6. Correspondingly, the effects of vehicle-related factors on

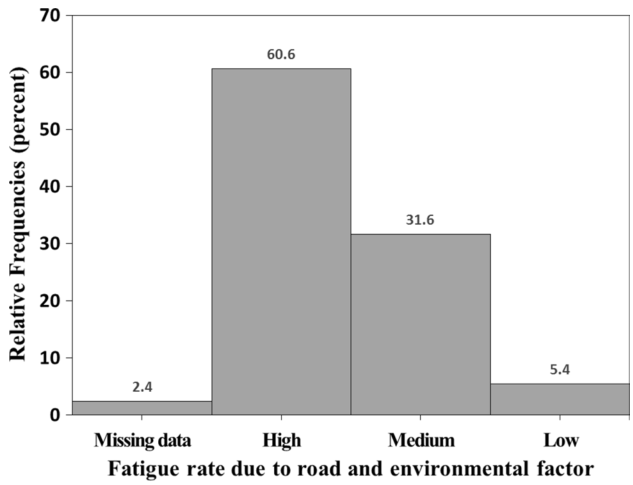

Fig. 4 Relative frequency of driver fatigue rate due to road and environmental factor (qualitatively)

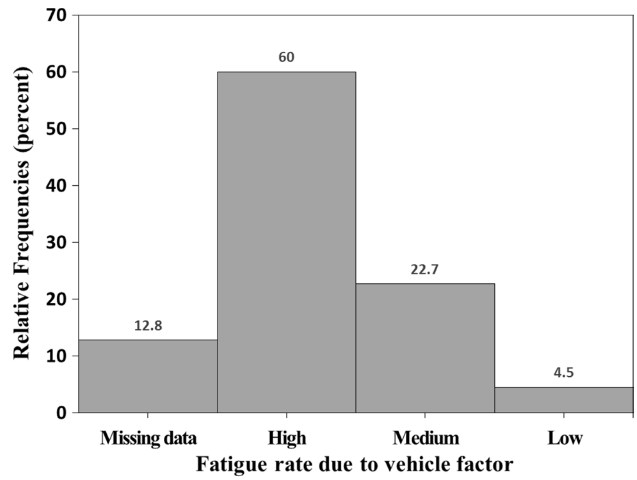

Fig. 6 Relative frequency of driver fatigue rate due to vehicle factor (qualitatively)

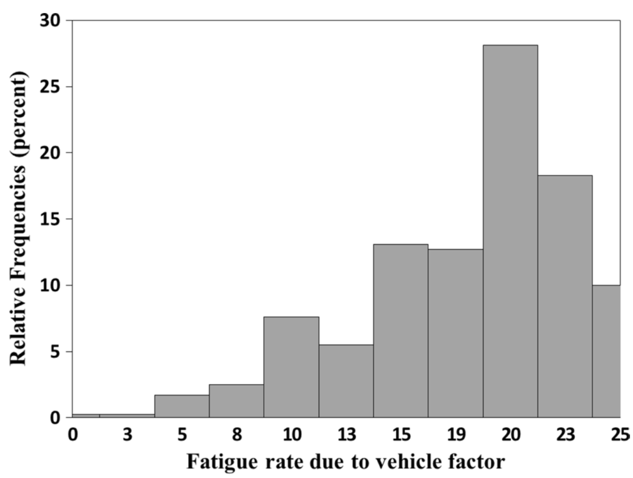

Fig. 5 Relative frequency of driver fatigue rate due to vehicle factor (quantitatively)

Table 5 One-sample Kolmogorov–Smirnov test

Factors affecting driver fatigue rate	Human	Road and environmental	Vehicle
Number of observations	335	335	335
Normal parameters			
Mean	3.6738	3.3795	3.5817
SD	0.87134	0.99782	1.00722
Most extreme differences			
Absolute	0.115	0.125	0.122
Positive	0.076	0.069	0.080
Negative	−0.115	−0.125	−0.122
Kolmogorov–Smirnov *Z*	2.098	2.284	2.224
p-value (2-tailed)	0.000	0.000	0.000

fatigue were also classified into three levels: weak (0–8.5), moderate (8.5–17), and strong (17–25). Figure 6 shows that 60% of the drivers considered vehicle-related factors as posing a strong effect on fatigue, whereas only 27.2% indicated weak and moderate effects.

5 Determination of the Most Important Factors Influencing the Fatigue and Sleepiness of Heavy-Vehicle Drivers

The most important factors that affect driver fatigue were determined. The underlying assumption of data normality was verified to examine whether the three factor categories exert similar effects. The results are shown in Table 5, which indicates that the two-tailed p value is less than the value regarded in this work as reflecting significance (<0.05). Thus, the normality assumption is rejected, and nonparametric tests should be carried out. The three factor categories are interrelated because the drivers who were asked questions related to the human category were also the same individuals to whom the questions regarding road and environmental conditions and vehicle-related factors were presented. Therefore, these respondents were referred to as dependent samples.

Variance analysis could not be conducted because the data were non-normal, and the samples were dependent. The Kruskal–Wallis test was also disregarded because of the dependence of the samples (Kvam and Vidakovic 2007). Instead, the Friedman test was performed because this test is related to sample dependence. The following hypotheses were adopted:

Table 6 Friedman test

Factors affecting driver fatigue rate	Mean rank
Human	2.11
Road and environmental	1.83
Vehicle	2.07

Table 7 Friedman test statistics

Number of observations	335
The Chi square test statistic	16.163
Degree of freedom	2
p-value	0.000

Null hypothesis (H_0) Human, road and environmental conditions, and vehicle-related factors exert equal effects on driver fatigue.

Alternative hypothesis (H_1) At least one of the factor categories exerts effects that differ from those posed by the other categories.

If the null hypothesis is accepted, then all the three factor categories would be determined as having equal effects on extent of driver fatigue, and but if the alternative hypothesis is accepted, then at least one factor category would exert different effects. The results of the Friedman test are provided in Tables 6 and 7. The *p*-value (0.000) indicates a significant difference among the effects of the three factor categories on degree of driver fatigue. As presented in the table, the effects of human factors on degree of driver fatigue are stronger than those of road and environmental conditions. This finding is confirmed by the box plot in Fig. 7. As indicated in the figure, the human, vehicle-related, and road and environmental categories have mean values of 3.674, 3.547, and 3.379, respectively. These values rank the categories of factors in order of strength of effects. That is, human factors exert the strongest effects on fatigue, whereas road and environmental conditions exert the weakest.

6 Ranking the Independent Variables Affecting Degree of Driver Fatigue

The independent variables related to the three factor categories were ranked using statistical and TOPSIS analyses.

6.1 Ranking Based on Statistical Analysis

In the statistical analysis, the total score of each independent variable was calculated through an examination of the drivers' Likert responses to questions regarding the effects of the independent variables on driver fatigue. The variable with the highest score is ranked the most important variable. The results are shown in Table 8.

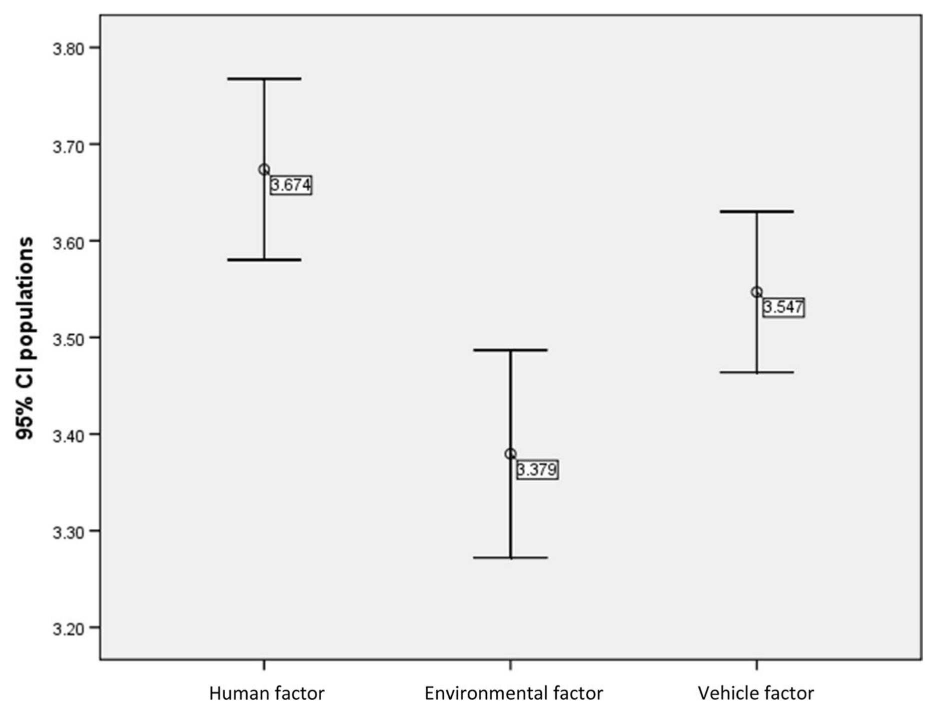

Fig. 7 A box plot comparing the effects of three categories affecting driver fatigue rate

Table 8 Ranking of the independent variables affecting fatigue and sleepiness of heavy-vehicle drivers using statistical analysis method (total scores)

Rank	Independent variable	The number of drivers who answered	Mean	SD	Total scores
1	Inappropriate behaviors of police	332	3.98	1.328	1320
2	Driving on non-standard roads with few road signs and poor quality asphalt pavement	334	3.85	1.287	1287
3	Inappropriate behaviors of passengers and goods owners	329	3.88	1.184	1275
4	Economic problems (costs of living, house rental, loans, …)	324	3.93	1.215	1274
5	Transport of contraband and associated stress and anxiety	317	4.01	1.528	1272
6	Alcohol abuse	315	3.89	1.687	1225
7	Drug abuse	319	3.77	1.675	1204
8	Family problems (death of family members, family dispute, gloom, …)	322	3.73	1.289	1201
9	Driving on high-traffic routes	332	3.61	1.345	1200
10	Driving in bad weather conditions (snow, fog, storm, etc.)	331	3.56	1.286	1178
11	Vehicle defects and age	334	3.49	1.397	1164
12	Shortage of appropriate driver cabin features (air conditioning and seating conditions)	333	3.49	1.346	1161
13	Age and physical abilities of drivers	331	3.34	1.41	1106
14	Excess freight and passengers carried	320	3.44	1.508	1102
15	Type of loads carried (perishable goods, fruits and vegetables)	304	3.56	1.497	1083
16	Driving between the hours of 5 a.m. and 2–4 p.m.	333	3.01	1.544	1002
17	Diseases associated with poor physical abilities	329	2.98	1.451	980
18	Driving on uniform and long roads	332	2.86	1.446	949

6.2 Ranking Based on TOPSIS

Multi-criteria decision-making methods can be used to rank the identified factors affecting driver fatigue. Multi-criteria evaluation techniques are a useful tool for selecting preferred options and can therefore be used to determine the relative importance and ranking of factors. Among many multi-criteria techniques, such as MAXMIN, SAW, AHP, SMART, and ELECTRE, TOPSIS was developed by Hwang and Yoon (1981) and it is a rational and computational efficient method. This method has the ability to measure the relative performance for each factor or alternative in a simple mathematical form.

In this research, the value of the participants' views is considered the same, and each factor is valued with the same dimension (0 to 5), so the use of statistical analysis, as presented in the previous section, can provide a ranking among the factors. However, using the TOPSIS method, it is possible to reduce the effect of the difference in the participant's scoring method.

It is based on the principle that a chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. This method involves comparing a set of alternatives by identifying weights for each criterion, normalizing the scores of each criterion, and calculating the geometric distance between each alternative and the ideal solution (i.e., the best score for each criterion). TOPSIS assumes that criteria monotonically increases or decreases, and normalization is usually required given that the parameters or criteria in multi-criteria problems are often of incongruous dimensions. Compensatory methods, such as TOPSIS, allow for trade offs between criteria, in which a poor result in one criterion can be negated by a good result in another criterion. This flexibility enables more realistic modeling than that offered by non-compensatory methods that include or exclude alternative solutions on the basis of stringent cutoffs (Jahanshahloo et al. 2006). The TOPSIS process in this work was carried out as follows:

Step 1: Determining a decision matrix for the independent variables:
An evaluation matrix consisting of m alternatives (drivers who responded to the questions) and n criteria (independent variables) was created, with the intersection of each alternative and criteria denoted as x_{ij}. We thus obtained a matrix $(x_{ij})_{m\times n}$, where x_{ij} is the Likert response (0–5) of person i about independent variable j (see Table 9).
Step 2: Normalizing the decision matrix:
For comparison, different scales of decision matrix $(x_{ij})_{m\times n}$ were modified to convert the matrix into normalized form $(n_{ij})_{m\times n}$ using the normalization method. Vector normalization was incorporated into the original TOPSIS method and was calculated using

Table 9 Decision matrix of independent variables

People	Independent variable			
	N_1	N_2	…	N_n
A_1	x_{11}	x_{12}	…	x_{1n}
A_2	x_{21}	x_{22}	…	x_{2n}
⋮	⋮	⋮		⋮
A_m	x_{m1}	x_{m2}	…	x_{mn}

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \tag{1}$$

Step 3: Calculating the weighted normalized decision matrix:
Weighted normalized value v_{ij} was calculated thus:

$$v_{ij} = \left(w_j n_{ij}\right)_{m\times n}, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, m \tag{2}$$

where w_j is the weight of the ith attribute or criterion, and $\sum_{j=1}^{n} w_j = 1$.
Step 4: Determining the positive ideal and negative ideal solutions:
For this step, the following equations were used:

$$A^+ = \left\{v_i^+, \dots, v_n^+\right\} = \left\{\left(\max_j v_{ij} \mid i \in I\right), \left(\min_j v_{ij} \mid i \in J\right)\right\} \tag{3}$$

$$A^- = \left\{v_i^-, \dots, v_n^-\right\} = \left\{\left(\min_j v_{ij} \mid i \in I\right), \left(\max_j v_{ij} \mid i \in J\right)\right\} \tag{4}$$

where I is associated with criteria that exert positive effects, and J is associated with criteria that have negative effects.
Step 5: Calculating separation measures using the n-dimensional Euclidean distance:
The separation of each alternative from the positive ideal solution was accomplished using Eq. (5):

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2}, \quad i = 1, 2, \dots, m \tag{5}$$

Similarly, separation from the negative ideal solution was conducted using Eq. (6):

$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}, \quad i = 1, 2, \dots, m \tag{6}$$

where d_i^+ and d_i^- are Euclidean distances from target alternative i to the positive and negative ideal solutions, respectively.
Step 6: Calculating relative closeness to the ideal solution:
The relative closeness of alternative A_i with respect to A^+ was defined as follows:

$$R_i = \frac{d_i^-}{\left(d_i^+ + d_i^-\right)}, \quad i = 1, 2, \dots, m \tag{7}$$

Given that $d_i^- \geq 0$ and $d_i^+ \geq 0$, $R_i \in [0, 1]$.
Step 7: Ranking the alternatives:
Using index R_i, the alternatives can be ranked in descending order (Gardziejczyk and Zabicki 2014; Shiau and Huang 2014).

Relative closeness to the ideal solution was calculated for each of the independent variables that affect degree of driver fatigue. The ranking of the variables is shown in Table 10. The inappropriate behaviors of passengers and goods owners rank the highest, whereas diseases associated with poor physical abilities rank the lowest.

6.3 Comparison of Two Ratings Methods

The prioritization of independent variables affecting driver fatigue was compared using two mentioned methods. As Table 11 shows the difference between preference orders of two methods is zero and four, the results of the two ranking methods were compared using the Spearman's rank correlation test, which is a widely accepted tool for determination of level of agreement between two rankings. Spearman's rank correlation is often used as a nonparametric method and requires no specific assumption regarding the nature of sample (Sadeghi et al. 2018; Montella 2005). Spearman's rank correlation coefficient is calculated by:

$$\rho_s = 1 - \frac{6 \times \sum_{i=1}^{n} d_i^2}{n \times \left(n^2 - 1\right)} \tag{8}$$

where ρ_s is the Spearman's rank correlation coefficient, di is the differences between ranks, and n is the number of paired samples (here $d_i = 18$). Using the statistical software SPSS, correlation coefficient was calculated to 0.905 with p-value < 0.0001, which indicated that the ranking of TOPSIS method is not significantly different from that of statistical analysis (total scores) method.

The statistical and TOPSIS results revealed that the first four factors that exert the strongest effects are inappropriate behaviors of passengers and goods owners, non-standard

Table 10 Ranking of the independent variables affecting fatigue and sleepiness of heavy-vehicle drivers using TOPSIS method

Rank	Independent variable	The distance between the alternative i and positive ideal solution, (d_i^+)	The distance between the alternative i and negative ideal solution, (d_i^-)	The relative closeness to the ideal solution, (R_i)
1	Inappropriate behaviors of passengers and goods owners	0.007	0.013	0.63
2	Driving on non-standard roads with few road signs and poor quality asphalt pavement	0.008	0.013	0.624
3	Inappropriate behaviors of police	0.008	0.013	0.615
4	Economic problems (costs of living, house rental, loans, …)	0.008	0.013	0.607
5	Driving on high-traffic routes	0.009	0.012	0.572
6	Family problems (death of family members, family dispute, gloom, …)	0.009	0.012	0.565
7	Transport of contraband and associated stress and anxiety	0.01	0.012	0.553
8	Shortage of appropriate driver cabin features (air conditioning and seating conditions)	0.009	0.011	0.548
9	Alcohol abuse	0.01	0.012	0.547
10	Age and physical abilities of drivers	0.009	0.011	0.544
11	Drug abuse	0.01	0.012	0.544
12	Driving in bad weather conditions (snow, fog, storm, etc.)	0.009	0.011	0.54
13	Vehicle defects and age	0.01	0.011	0.527
14	Excess freight and passengers carried	0.011	0.011	0.509
15	Type of loads carried (perishable goods, fruits and vegetables)	0.011	0.011	0.497
16	Driving between the hours of 5 a.m. and 2–4 p.m.	0.012	0.01	0.451
17	Driving on uniform and long roads	0.011	0.009	0.451
18	Diseases associated with poor physical abilities	0.012	0.009	0.455

roads, inappropriate behaviors of police, and economic problems of heavy-vehicle drivers.

7 Conclusion

The independent variables affecting the fatigue and sleepiness experienced by heavy-vehicle drivers can be divided into three groups: human, road and environmental conditions, and vehicle-related factors. To investigate whether these factors have the same effects on fatigue and sleepiness, a null hypothesis (human, road and environmental conditions, and vehicle-related factors exert equal effects on driver fatigue.) and an alternative hypothesis (at least one of the factor categories exerts effects that differ from those posed by the other categories.) were evaluated using the Friedman test. The results indicated rejection of the null hypothesis and acceptance of the alternative hypothesis; that is, we found a significant difference among the effects of the three factor categories. Overall, the findings reflected that human factors pose the strongest effects on degree of driver fatigue.

The TOPSIS analysis results indicated that the independent variables rank in descending order; thus, inappropriate behaviors of passengers and goods owners, driving on non-standard roads with few road signs and poor-quality asphalt pavement, inappropriate behaviors of police, economic problems, driving on high-traffic routes, family problems, transport of contraband and consequent stress and anxiety, shortage of appropriate driver cabin features, alcohol abuse, age and physical abilities of drivers, drug abuse, driving in bad weather conditions, vehicle defects and age, excess freight and passengers carried, type of loads, driving between the hours of 5 a.m. and 2 to 4 p.m., driving on uniform and long roads, and diseases associated with poor physical abilities.

Table 11 Comparison of ranking the independent variables affecting fatigue and sleepiness of heavy-vehicle drivers using TOPSIS and statistical analysis

Independent variable	Ranking based on TOPSIS	Ranking based on statistical analysis (total scores)
Inappropriate behaviors of passengers and goods owners	1	3
Driving on non-standard roads with few road signs and poor quality asphalt pavement	2	2
Inappropriate behaviors of police	3	1
Economic problems (costs of living, house rental, loans, …)	4	4
Driving on high-traffic routes	5	9
Family problems (death of family members, family dispute, gloom, …)	6	8
Transport of contraband and associated stress and anxiety	7	5
Shortage of appropriate driver cabin features (air conditioning and seating conditions)	8	12
Alcohol abuse	9	6
Age and physical abilities of drivers	10	13
drug abuse	11	7
Driving in bad weather conditions (snow, fog, storm, etc.)	12	10
Vehicle defects and age	13	11
Excess freight and passengers carried	14	14
Type of loads carried (perishable goods, fruits and vegetables)	15	15
Driving between the hours of 5 a.m. and 2–4 p.m.	16	16
Driving on uniform and long roads	17	18
Diseases associated with poor physical	18	17

From the statistical analysis scores, the independent variables rank as follows: inappropriate behaviors of police, driving on non-standard roads with few road signs and poor-quality asphalt pavement, inappropriate behaviors of passengers and goods owners, economic problems, transport of contraband and consequent stress and anxiety, alcohol abuse, drug abuse, family problems, driving on high-traffic routes, driving in bad weather conditions, vehicle defects and age, shortage of appropriate driver cabin features, age and physical abilities of drivers, excess freight and passengers carried, type of loads, driving between the hours of 5 a.m. and 2 to 4 p.m., diseases associated with poor physical abilities, and driving on uniform and long roads.

The results of this research can be used by policy makers of the transportation industry especially by safety officials. Eliminating or reducing the factors affecting the fatigue of professional drivers can lead to a reduction of related accidents and improve the health of drivers. Policies and countermeasures can be found in management, advertising, education, use of new technologies, etc. Since human factors such as inappropriate behavior of individuals and police are the most important factors affecting driver fatigue, investment, and efforts to improve this behavior or to mechanize interactions between drivers and others can lead to a reduction in fatigue. Road designers and road maintenance authorities should be aware that their poor performance, in addition to having a direct impact, indirectly increases the risk of road accidents by increasing drivers' fatigue.

It should be noted that although this study has identified and ranked some factors about driver fatigue, there still exists many questions about drivers' psychological factors and time- space dependent factors. These issues can be addressed in future researches. Also, each of the factors affecting the drivers' fatigue, which is introduced in this study, itself includes several sub-factors. Identifying these sub-factors and introducing countermeasures to reduce their effects can lead to a solution to reduce driver's fatigue. For example, identifying the causes of inappropriate behavior of passengers and goods owners and removing them can result in a reduction of the fatigue in drivers.

Identifying differences and similarities in the opinions of different drivers about fatigue factors can be investigated in a separate study. For example, there may be a significant difference between the drivers of long-distance and short-distance routes. Considering different weight for the participants' views in the presented TOPSIS ranking method may lead to a better understanding of the factors affecting fatigue drivers.

Another area for future studies is the use of other analytical and inferential methods such as discrete choice analysis, regression models, structural equation models, and data mining methods that could be used to study the affecting factors and their relative effect on driver's fatigue. These methods are more complicated than descriptive statistics method but are often more capable to show relationships and relative importance among multiple factors. For more appropriate use of these models, it is also recommended to quantify driver fatigue.

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